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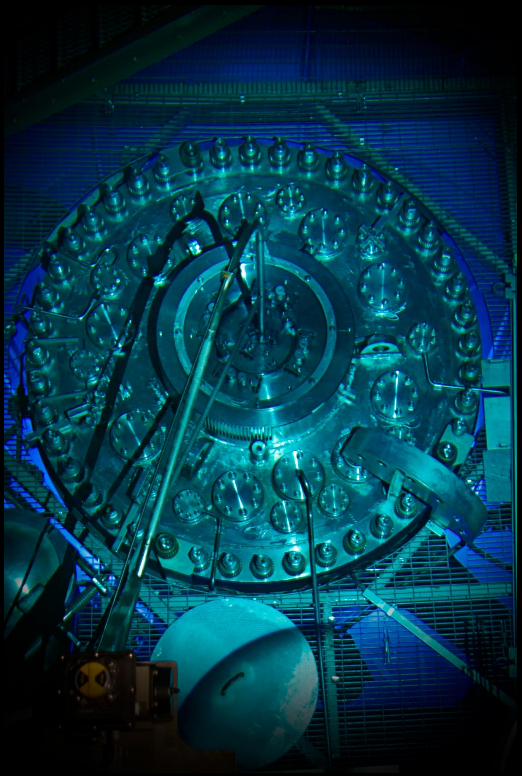
Search for Sterile Neutrinos with the Borexino Detector

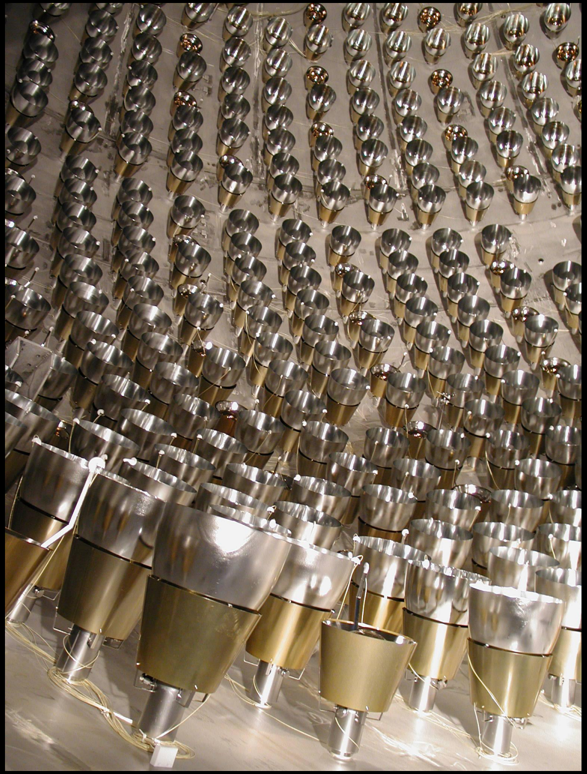
PANIC 2014

Hamburg

Mikko Meyer

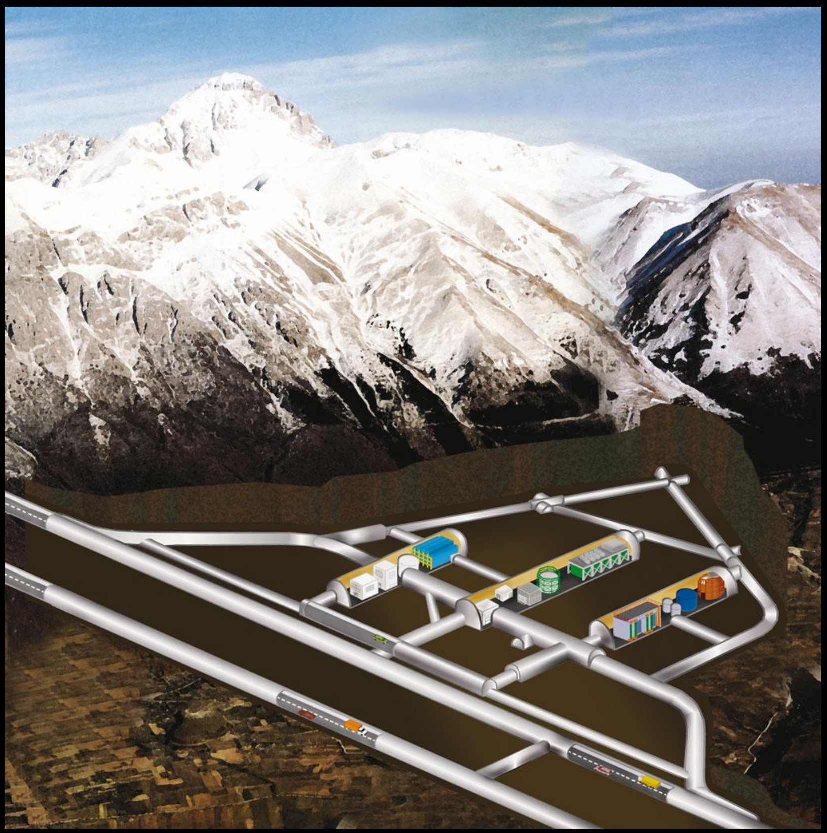
on behalf of the BOREXINO Collaboration



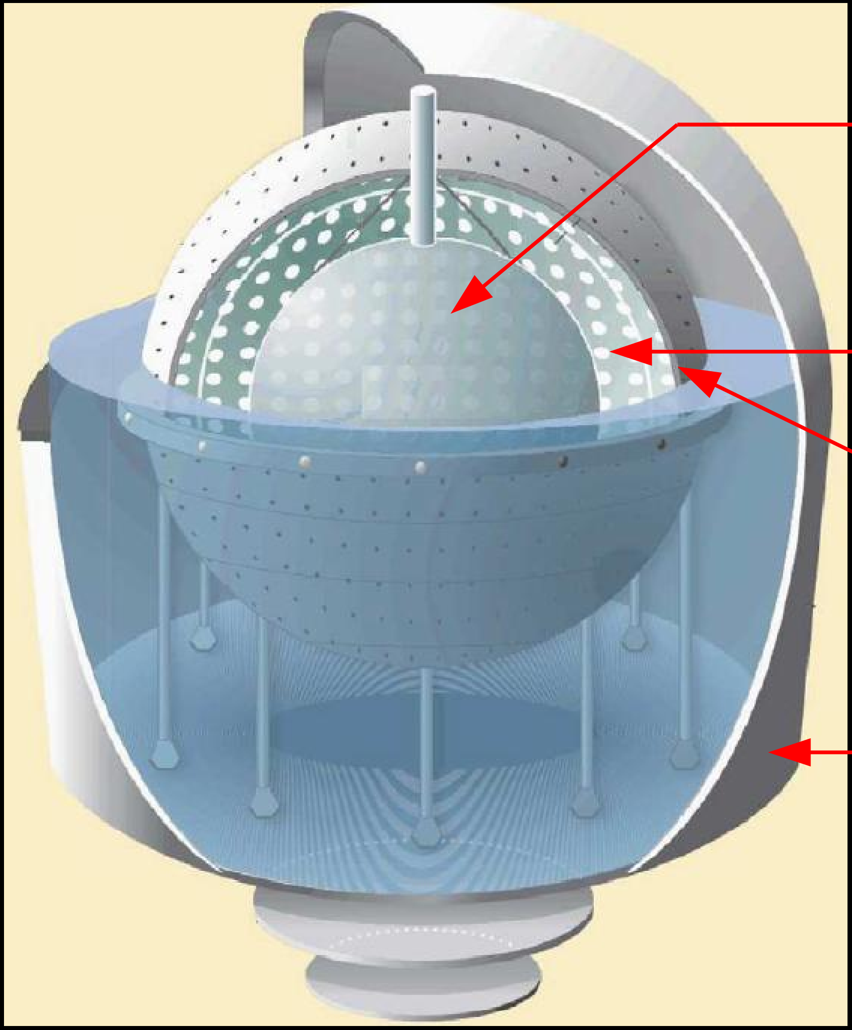


Borexino Detector Site

- 1400 m of rock shielding
- 3800 m.w.e. → 1.2 muons /($m^2 \cdot h$)



Borexino Detector



Active volume
270 t of liquid scintillator (PC)
nylon vessel of R=4.25 m
Radiopurity: U/Th < 10^{-17} g/g

Inactive buffer volume
Shielding of external γ-rays

Stainless steel sphere
R = 6.85 m
2212 PMTs

Outer muon veto
2.1 kt of water, R=9 m
208 PMTs
Muon-Cherenkov veto

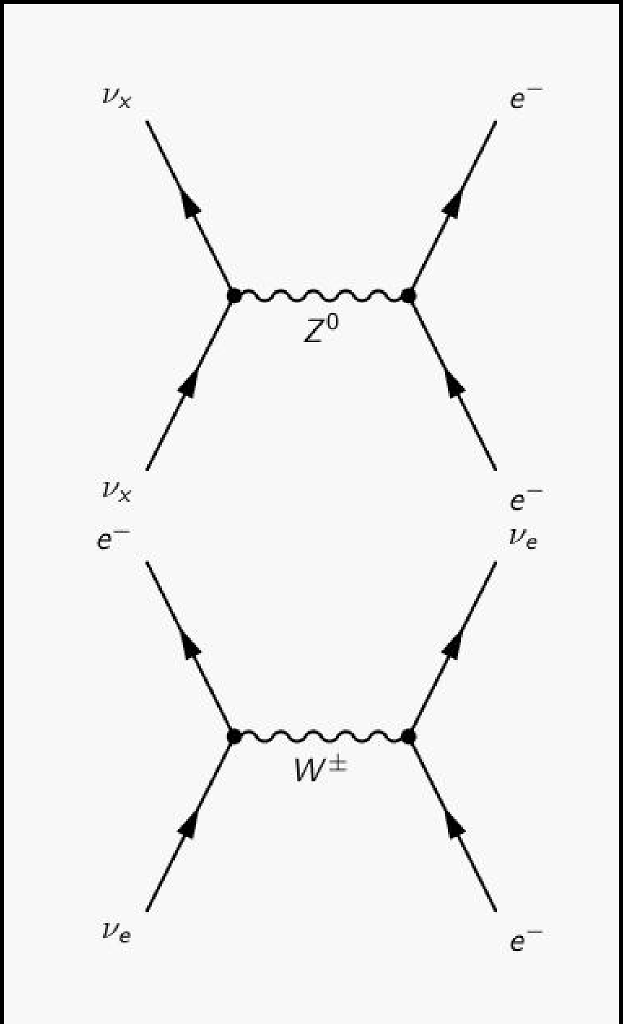
Neutrino Detection

Neutrino-Electron Scattering

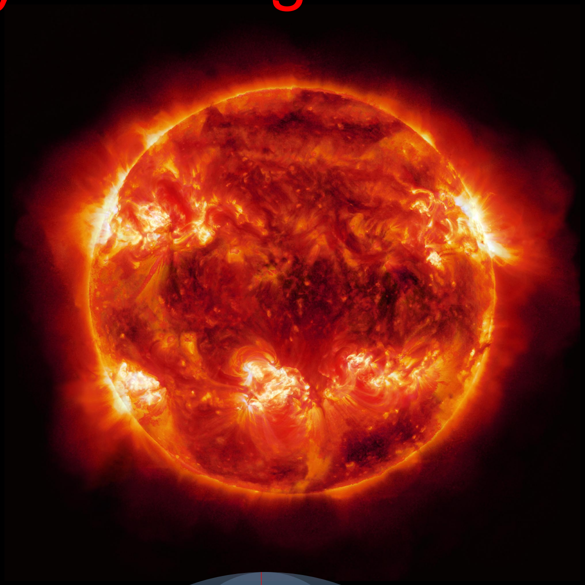
- Energy transfer analogous to Compton scattering
- Recoil of electron → Scintillation light
- For ν_e: CC + NC

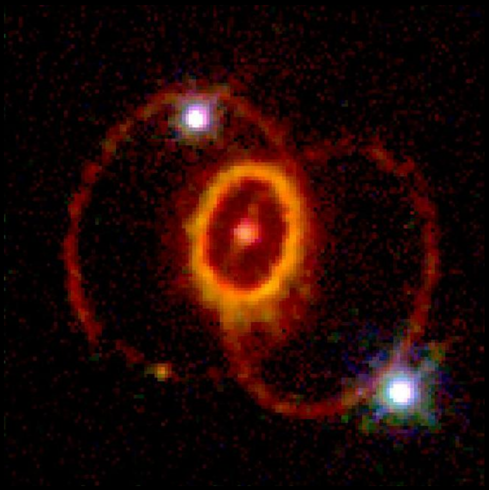
Inverse β-decay

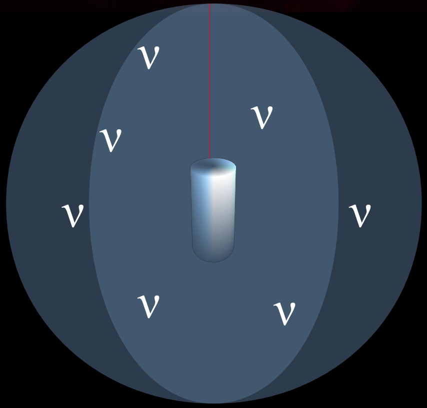
- Prompt signal: Positron annihilation
- Delayed signal: Neutron capture on hydrogen
- Signal is time and space correlated
- Energy threshold: 1.806 MeV

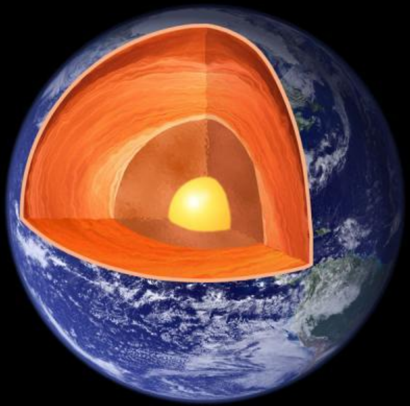


Physics Program









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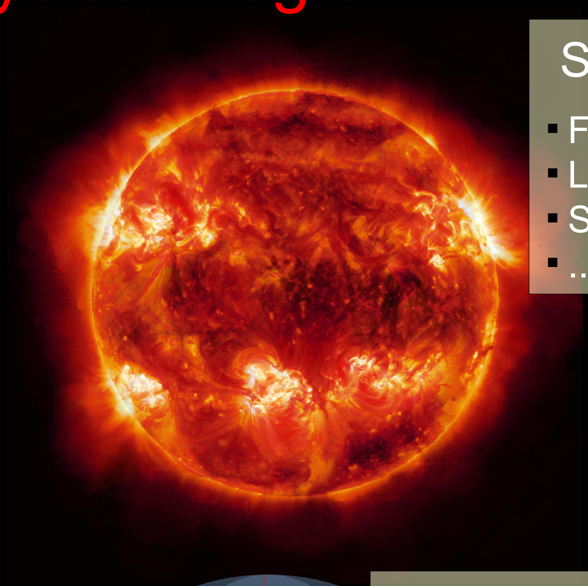
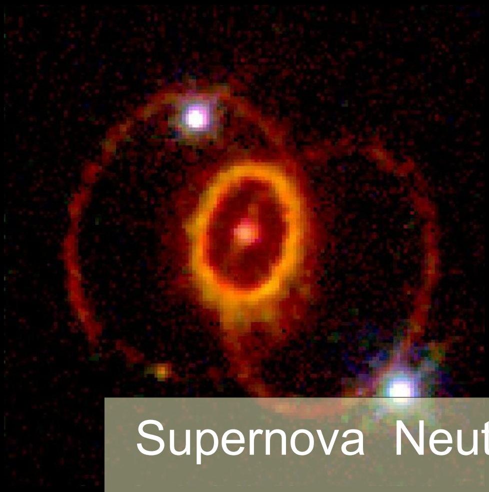


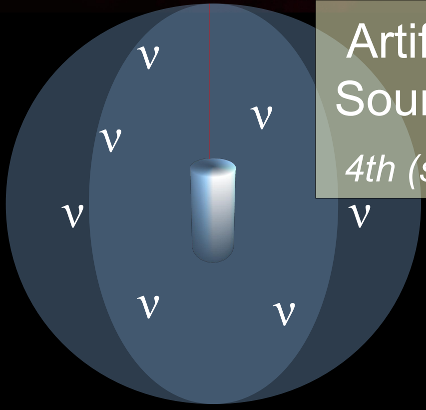
Solar Neutrinos

- First observation of ^{7}Be-ν
- Limit on CNO
- Seasonal variations
- ...



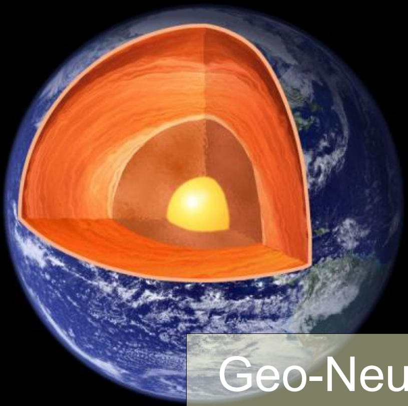
Supernova Neutrinos

Waiting for the next one...



Artificial Neutrino Sources

4th (sterile) Neutrino?

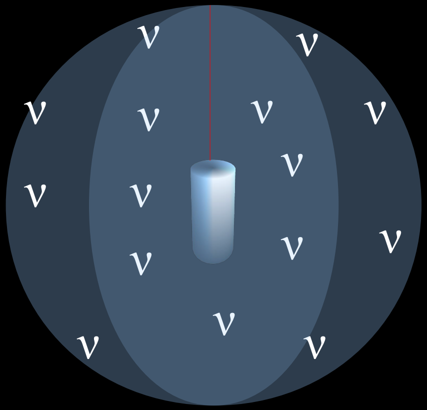


Geo-Neutrinos

- Null geo-ν excluded at $6 \cdot 10^{-6}$ probability

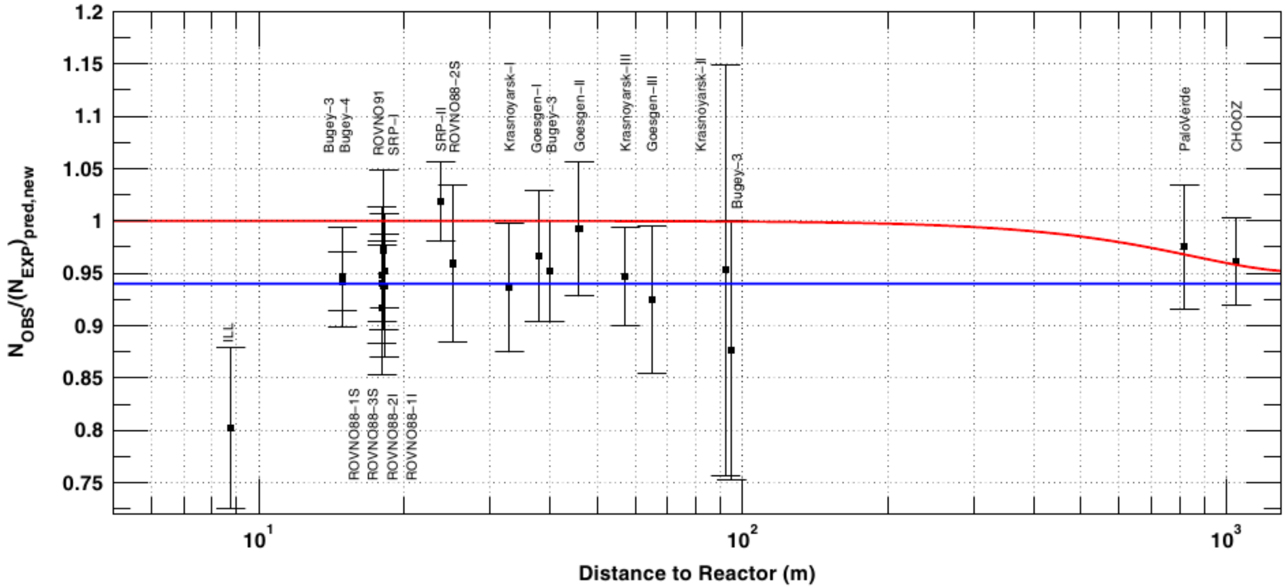
SOX

Search for Sterile Neutrinos



Phys.Rev.D83:073006,2011

Hints for Sterile Neutrinos



- Re-evaluation of neutron life time

→ Cross section of inverse beta decay (IBD) might be affected

- Reactor anomaly: Flux re-calculations
- LSND anomaly
- Gallex and SAGE calibration campaign with artificial neutrino source

C. Giunti, M. Laveder, Y. F. Li, H.W. Long
Phys. Rev. D 88, 073008 (2013)

Hints for Sterile Neutrinos

Global Picture

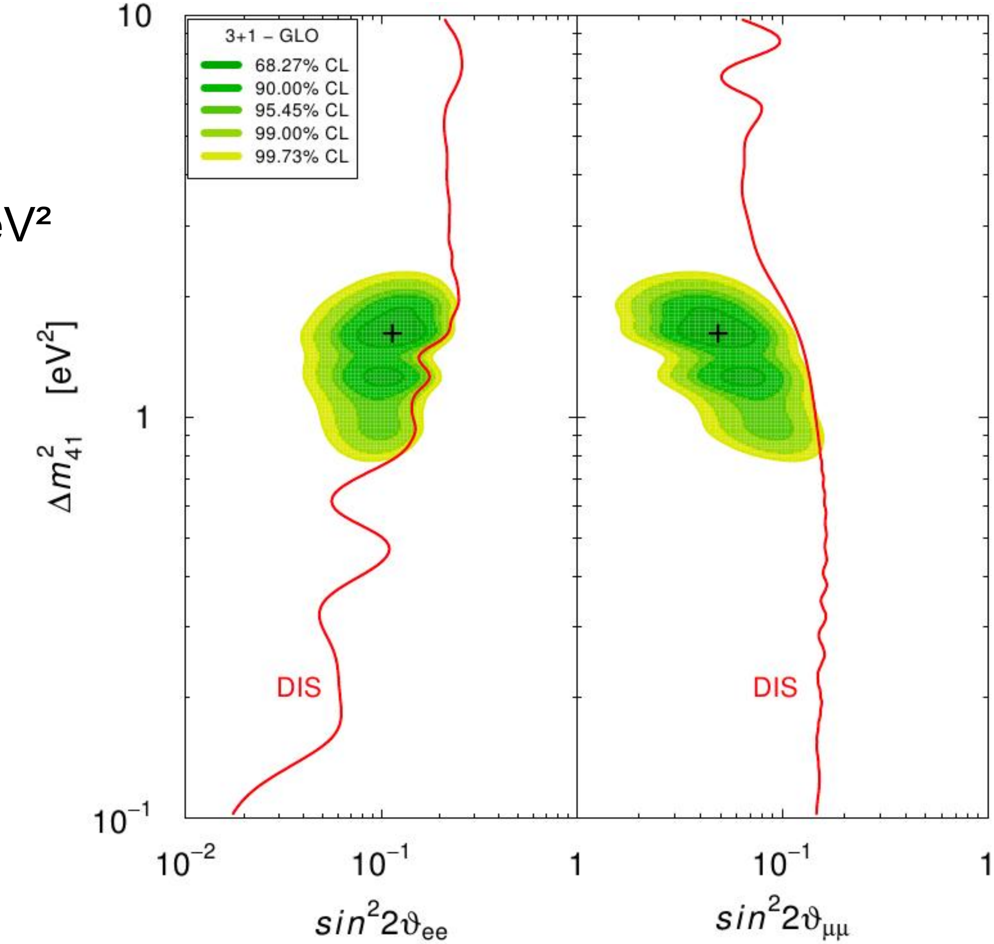
- **Fit in the 3+1 scenario**
- **Favored region:** $0.82 < \Delta m^2_{14} < 2.19 eV^2$

→ Oscillation at short distances, if

- Neutrinoenergy ~ 1MeV

Experimental Possibilities:

- Artificial Neutrino Sources in large low background detector (SOX)
- Short baseline reactor experiments (Nucifer and STEREO)
  see talk by A. Letourneau
- IsoDAR (Isotropic Decay at Rest: ^{8}Li)
  see talk by J. Spitz: *IsoDar and DAEdALUS*

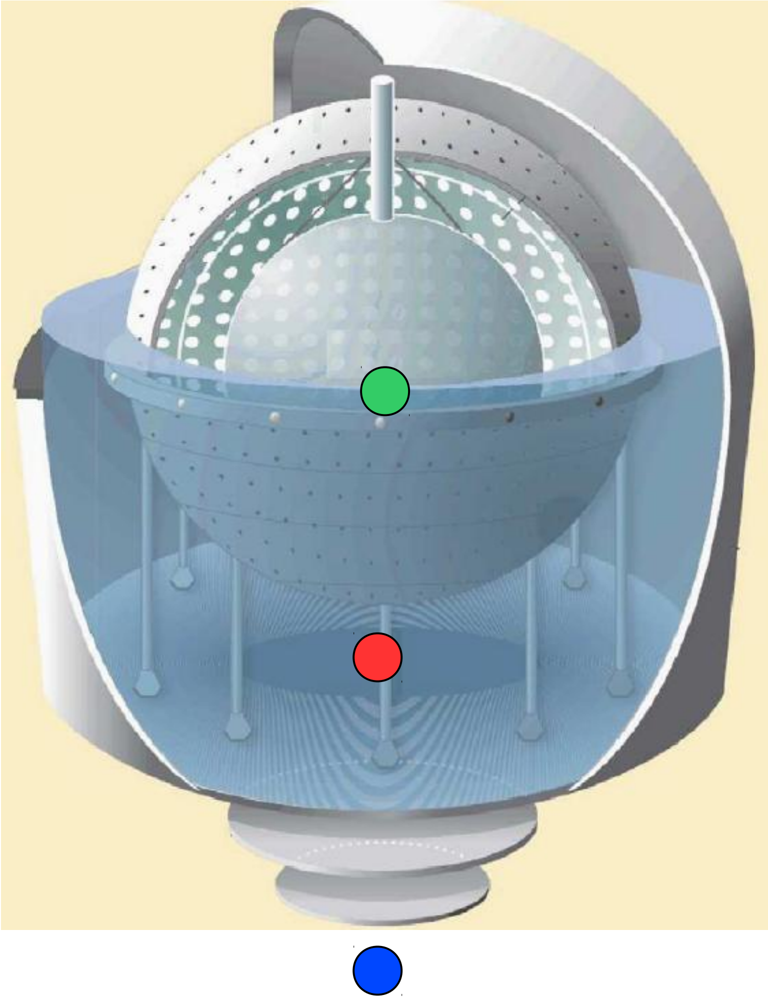


Motivation for SOX

- **S**hort distance neutrino **O**scillations with Bore**X**ino

$$P(\nu_e \rightarrow \nu_e) \approx 1 - \sin^2(2\theta_{14}) \sin^2\left(\Delta m_{41}^2 \frac{L}{4E}\right)$$

- Motivation:
  - Search for sterile neutrinos and other short distance effects
  - Measurement of neutrino magnetic moment
  - Measurement of g_V and g_A at low energy



SOX Concept

Phase A: ^{51}Cr and ^{144}Ce-^{144}Pr

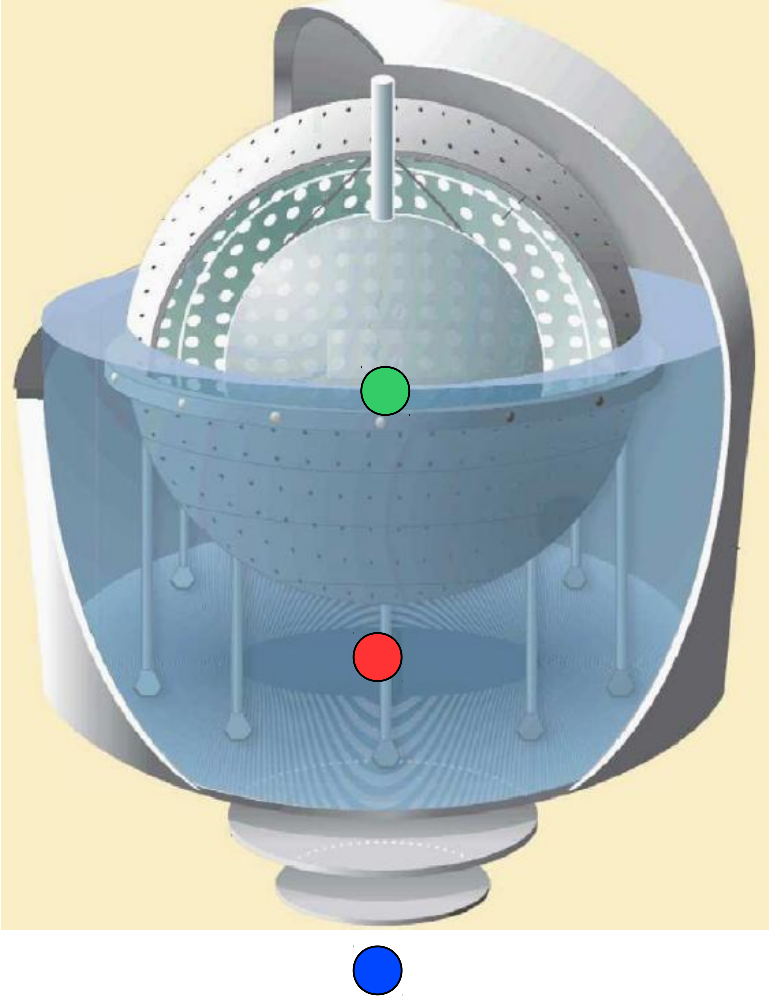
- 8.25 m beneath detector
- EC source (^{51}Cr) and
- β^- (^{144}Ce-^{144}Pr)

Phase B: ^{144}Ce-^{144}Pr

- Source in water tank
- β^- source

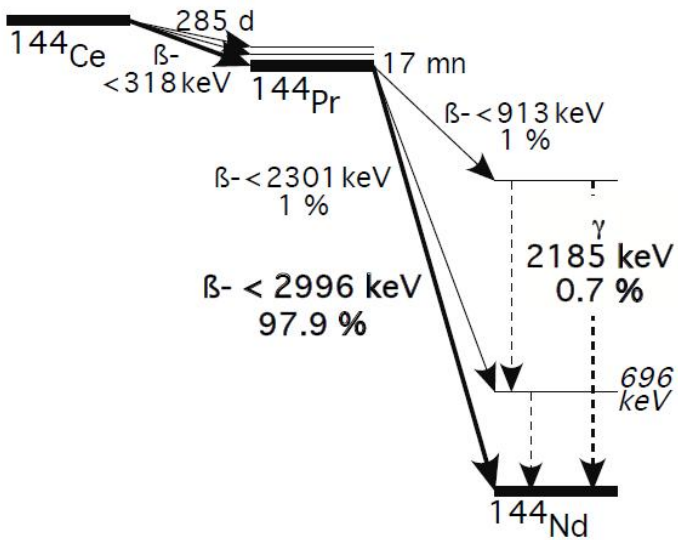
Phase C: ^{144}Ce-^{144}Pr

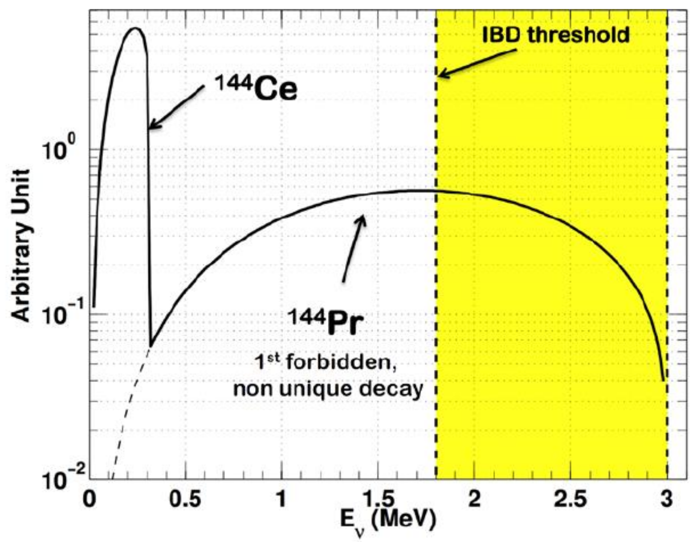
- Source in center of detector
- β^- source



Artificial Neutrino Sources

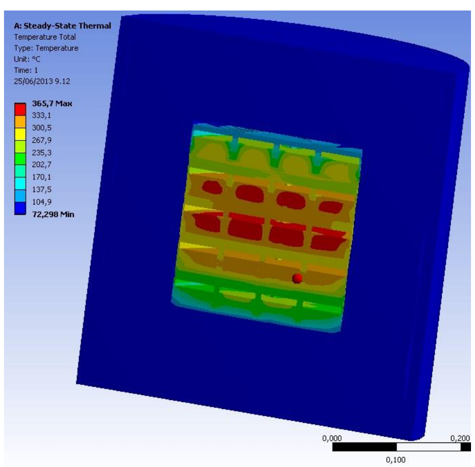
Source	Production	τ [days]	Decay mode	Energy [MeV]	Mass [kg/MCi]
^{51}Cr	Neutron irradiation of ^{50}Cr in reactor	40	EC γ 320 keV (10%)	0.746	0.011
^{144}Ce-^{144}Pr	Chemical extraction from spent nuclear fuel	411	β^-	<2.9985	7.6

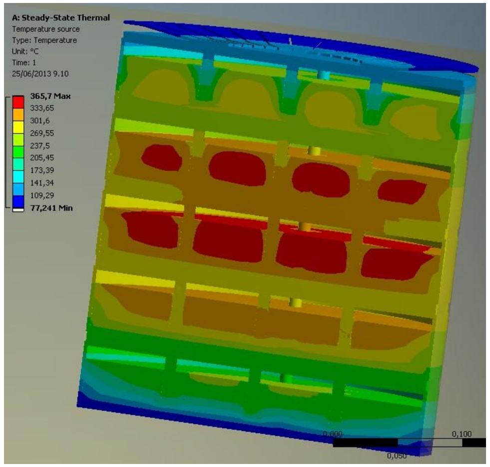


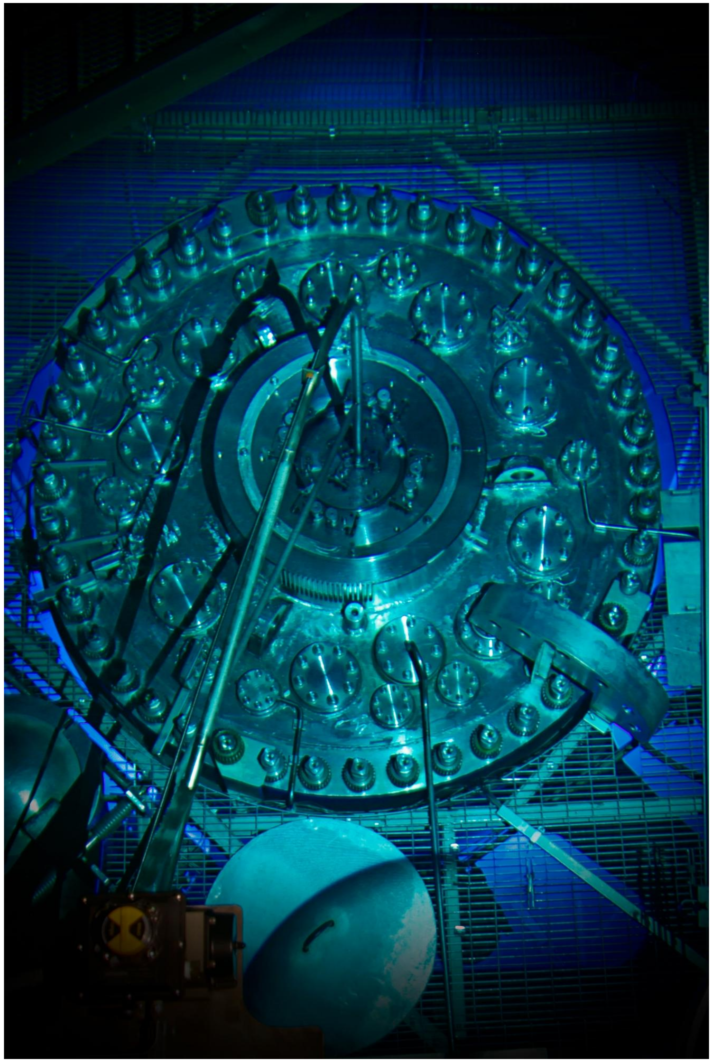


Chromium Source

- **Irradiation** possible in HFIR or Mayak
- **Tungsten shielding:** biological (<200μSv/h in contact with shield) and background (320keV γ)
- **Transportation:** 5 days to 2 weeks
- **Thermal design:** 0.19kW/MCi, 90°C outside, 300°C inside



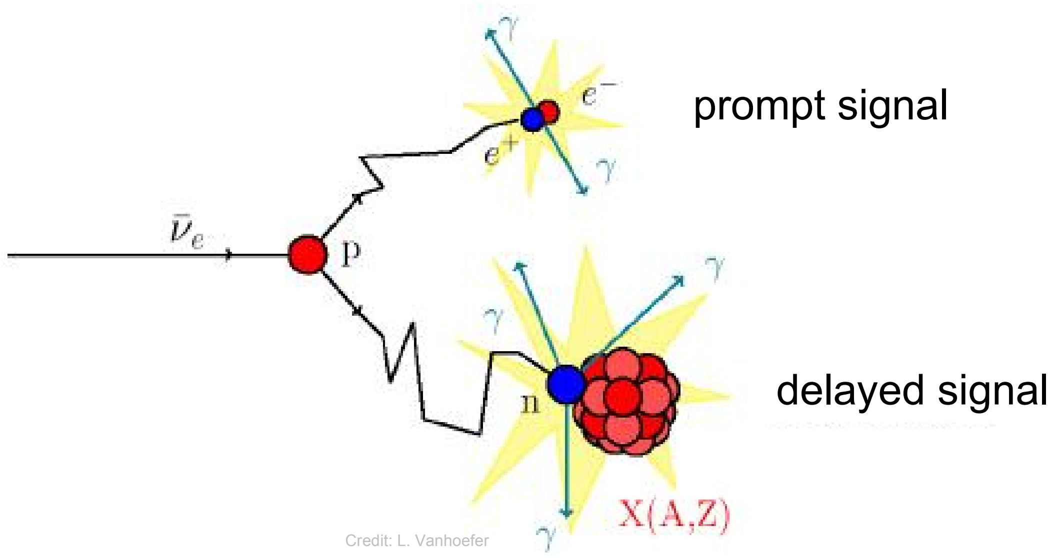


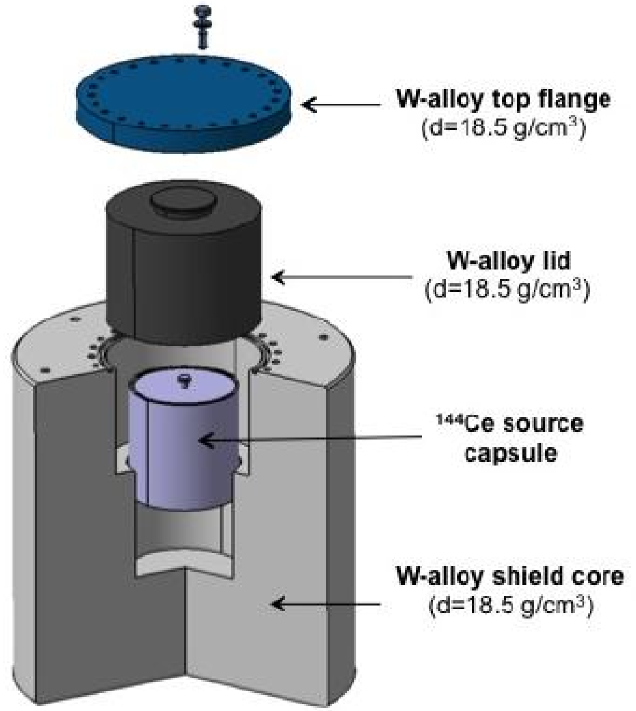


Cerium Source

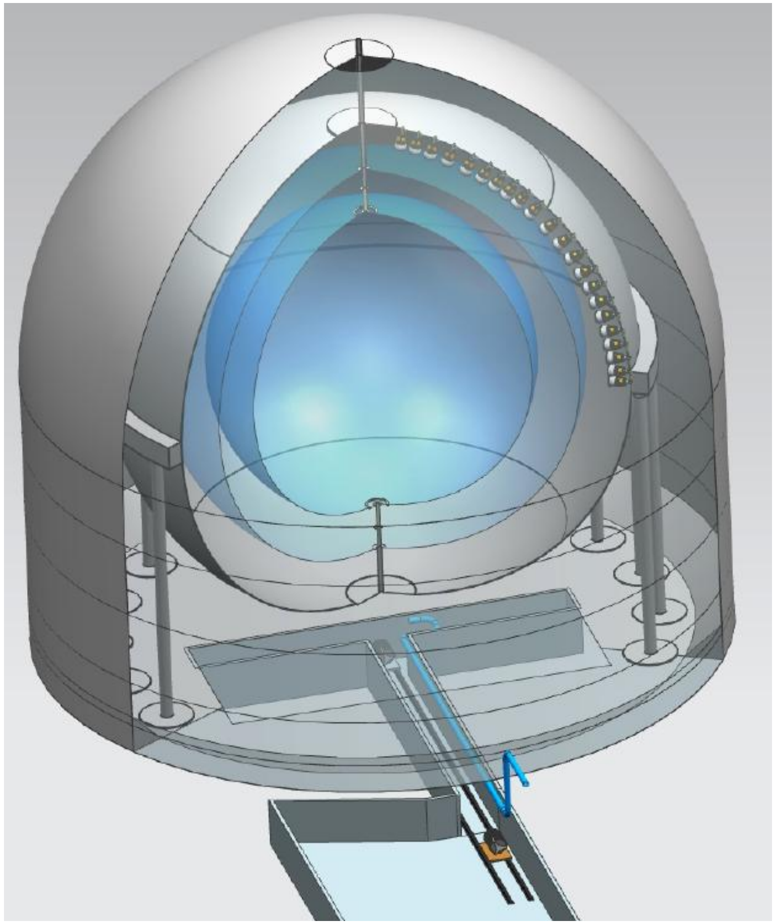
CeLand design (arXiv1312.089)

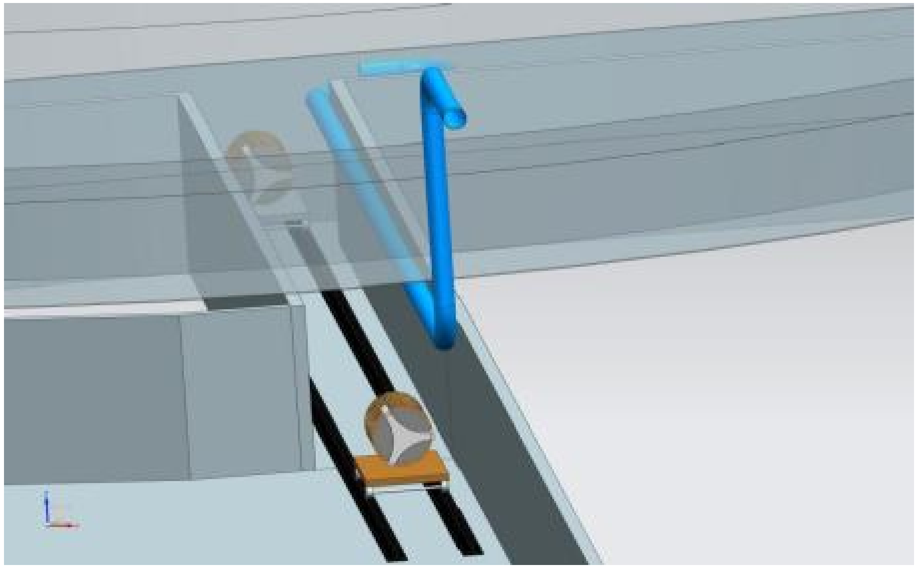
- **Production:** Cerium extraction from spent fuel elements @ Mayak (Russia)
- **Shielding and thermal design:** more challenging
- **Transportation:** less critical
- **Signature:** Inverse Beta Decay





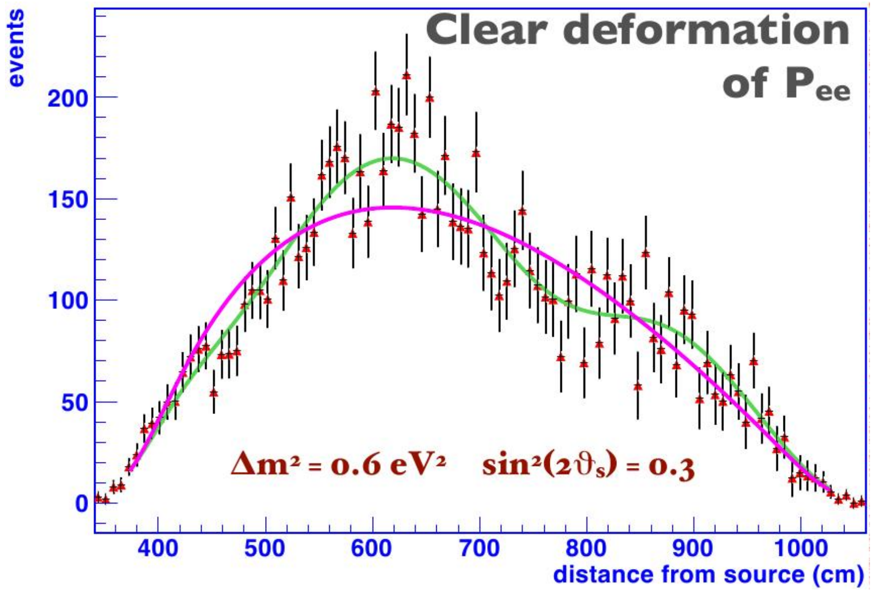
Location for Phase A

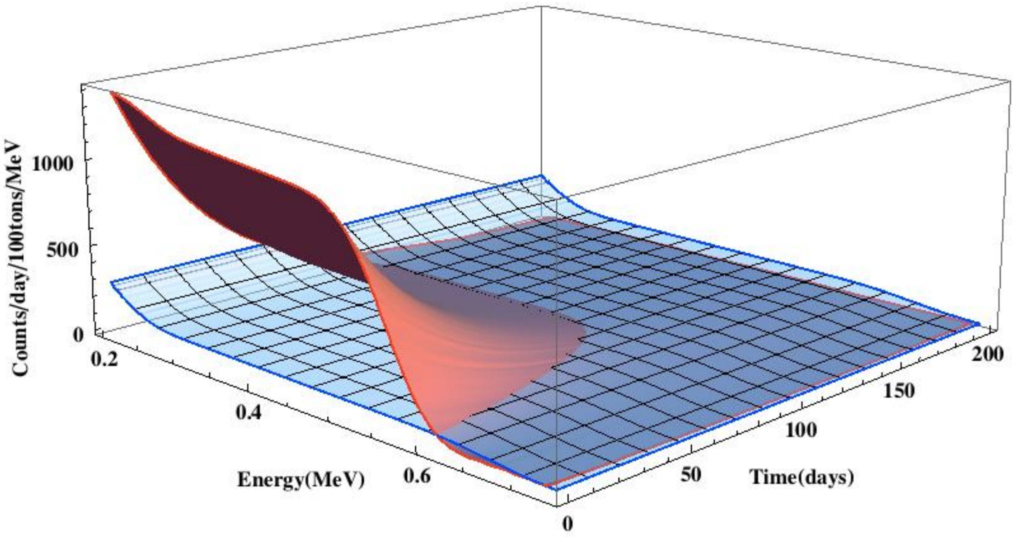




^{51}Cr Source: Oscillation Pattern

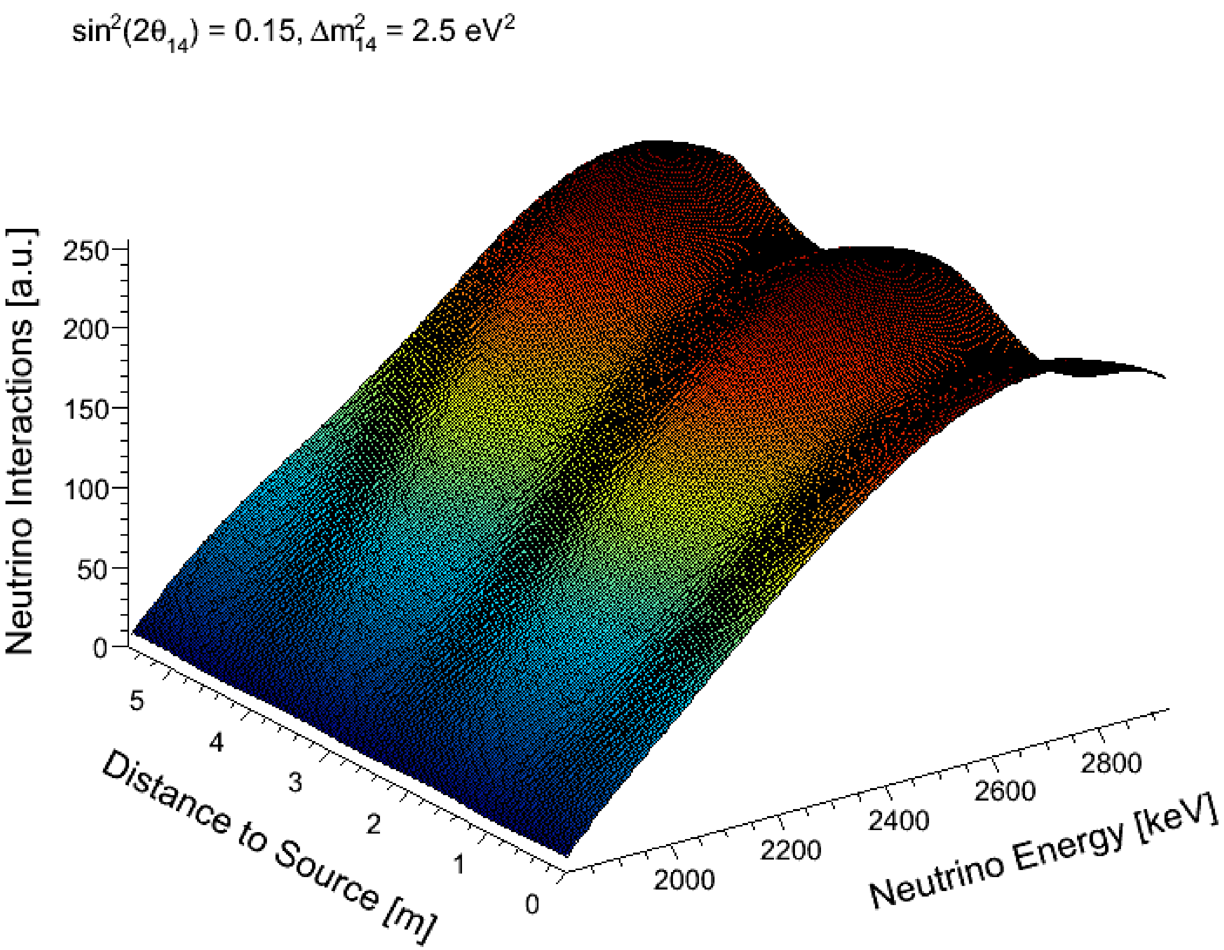
- **Oscillation pattern:** visible by plotting distance from source
- **Time evolution:** signal relatively fast decreasing, background remains app. constant
- **Spectrum feature:** clear compton edge
- **Analysis:** rate + shape





Plot taken from D. Bravo (ICHEP 14 talk)

^{144}Ce-^{144}Pr Source: Oscillation Pattern



Oscillometry

Wavelength:
smaller than detector size,
but bigger than resolution

→ Direct measurement of Δm^2_{14} and θ_{14}

Source in detector center

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Neutrino 2014
Additional information: JHEP08 (2013) 038

Expected Sensitivity (Phase A)

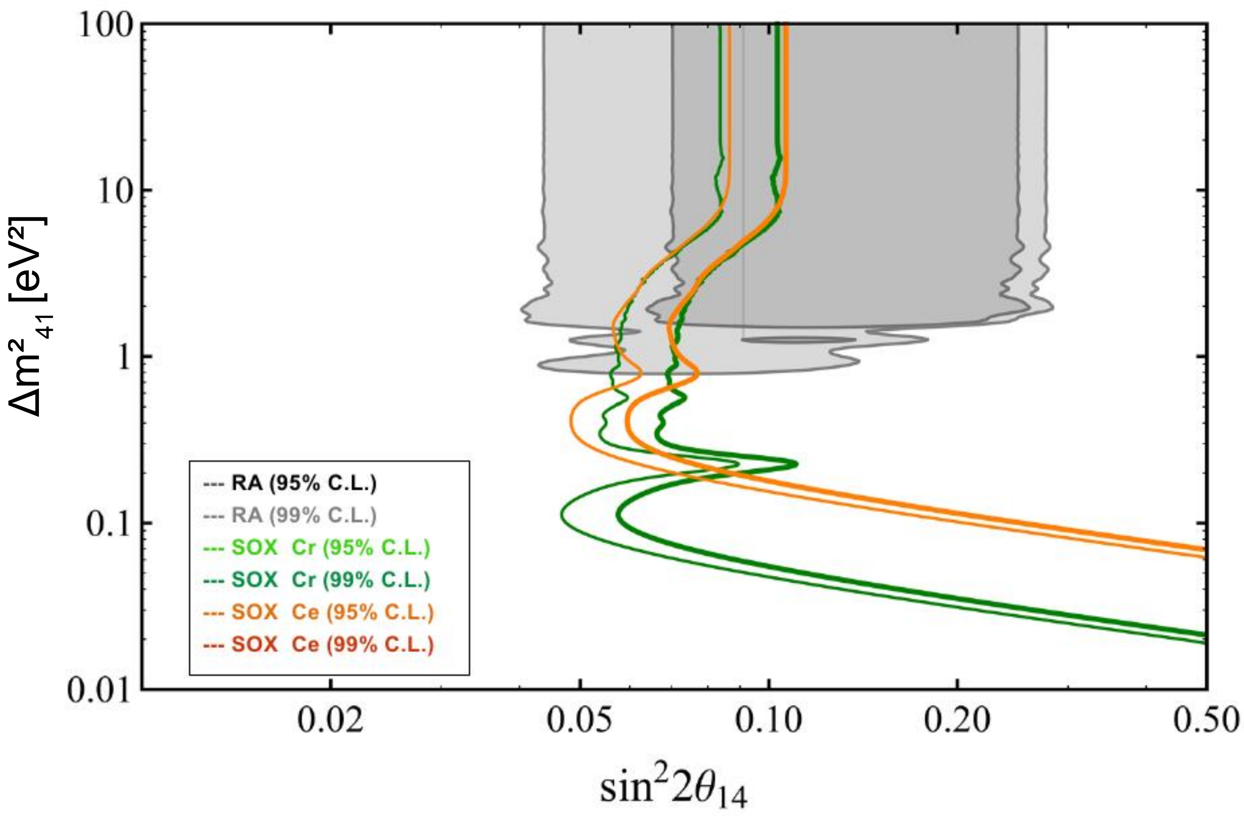
sources in pit

^{51}Cr

- Time: ~100 days
- Activity: 10 MCi
- r_{FV} < 3.3 m

^{144}Ce-^{144}Pr

- Time: ~1.5 years
- Activity: 100 kCi
- r_{FV}< 4.25 m



r_{FV}: Radius of fiducial volume

Neutrino 2014
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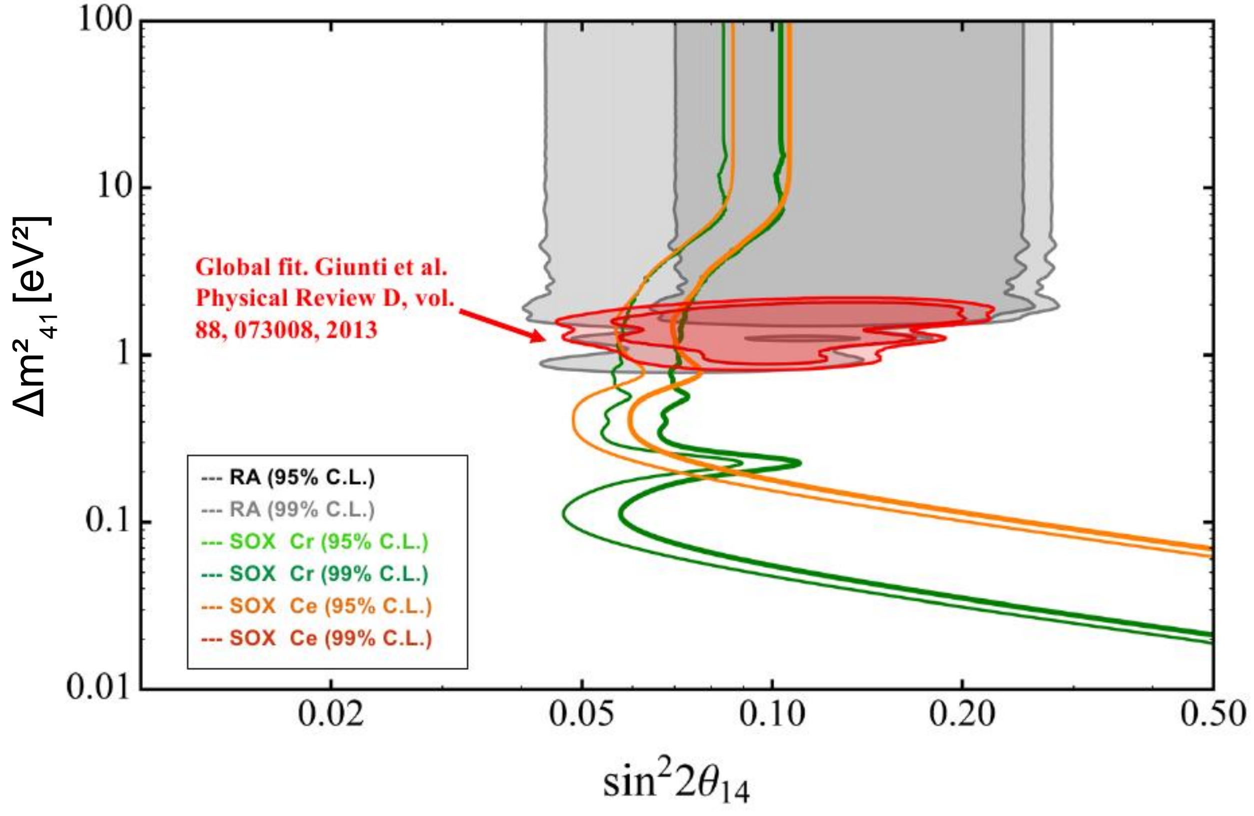

r_{FV}: Radius of fiducial volume

Further Reading...

JHEP

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SOX: Short distance neutrino Oscillations with BoreXino

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Summary

- Borexino: liquid scintillator detector with unprecedented radiopurity
- Broad range of solar neutrino fluxes (^{7}Be, ^{8}B, pep, CNO) and geo-neutrinos
- SOX will test reactor antineutrino anomaly
- Two sources will be placed near or inside Borexino
  - ^{51}Cr (neutrino)
  - ^{144}Ce-^{144}Pr (antineutrino)
- Most attractive: Oscillometry → Oberservation of waves within the detector

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Thank you for your attention!

Additional Physics

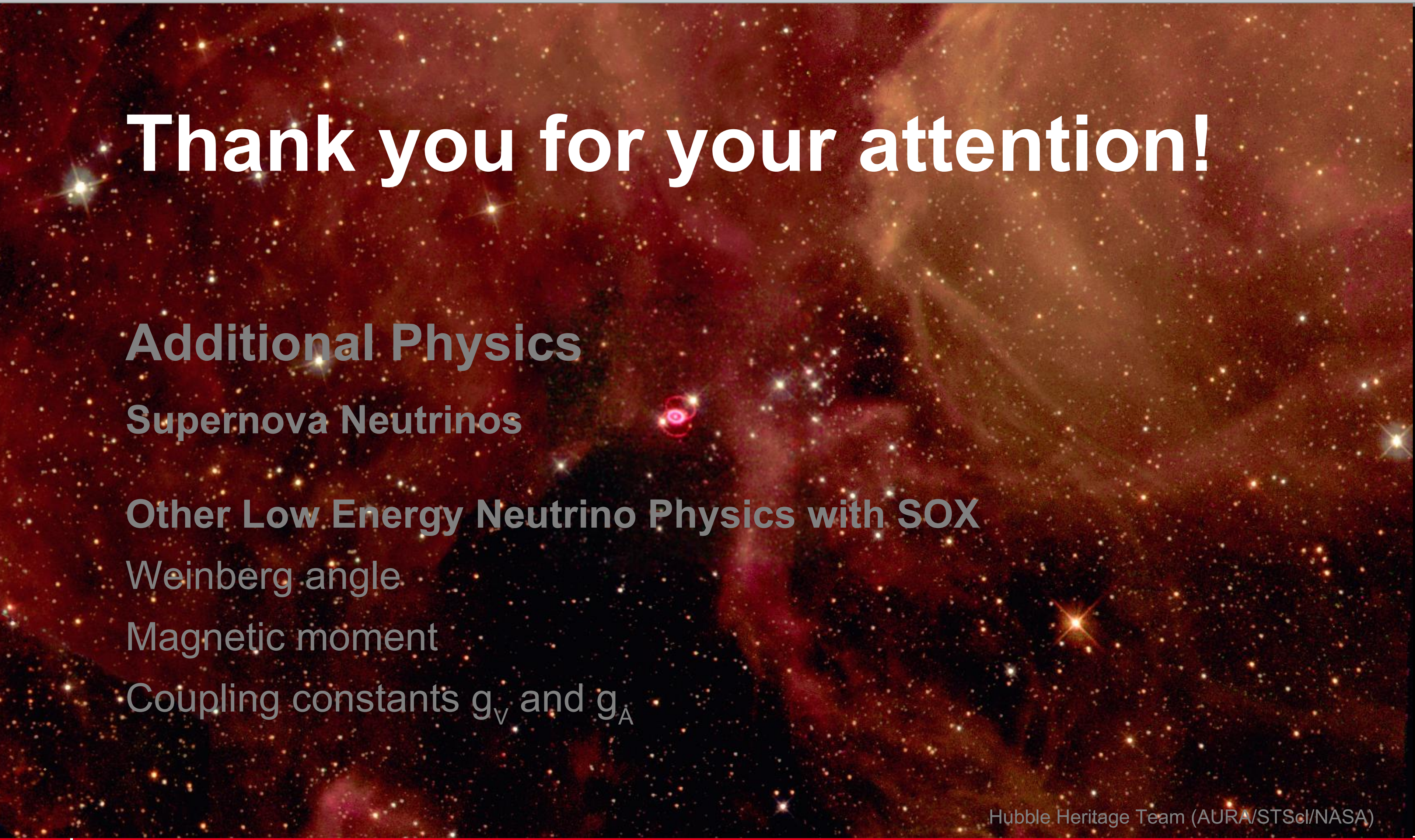
Supernova Neutrinos

Other Low Energy Neutrino Physics with SOX

Weinberg angle

Magnetic moment

Coupling constants g_V and g_A



Hubble Heritage Team (AURA/STScI/NASA)

Borexino Collaboration

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SINP MSU

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PRINCETON UNIVERSITY

LNGS

Technische Universität München

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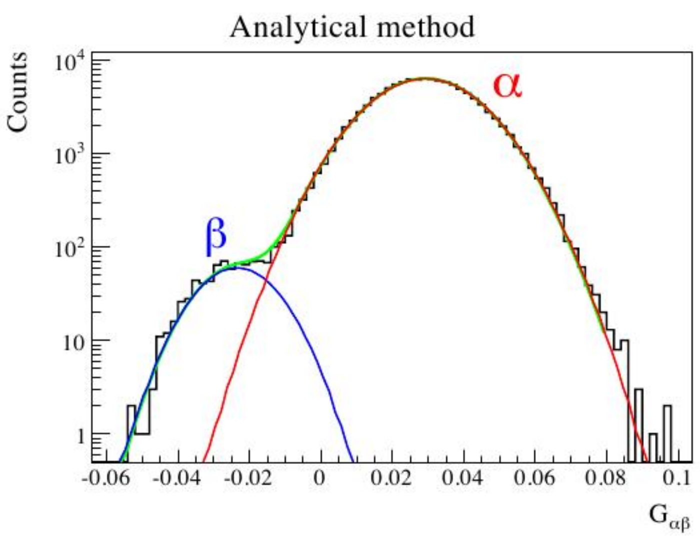
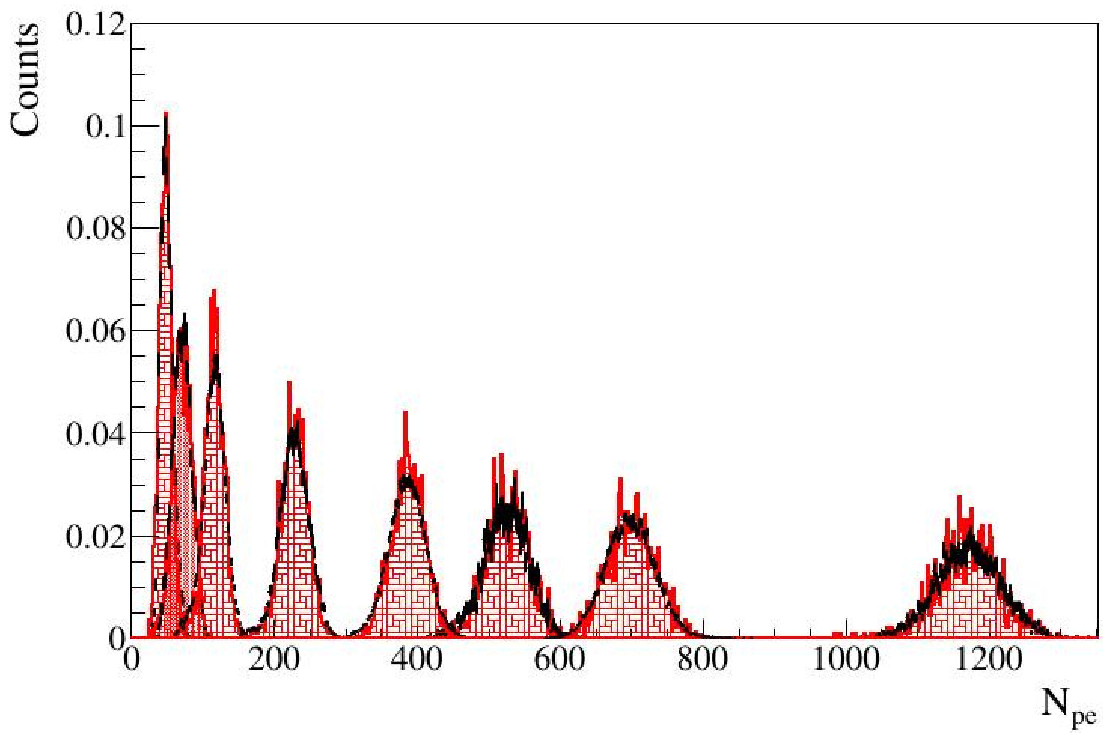
Neutrino detection

Scintillation light Detection

- # of photons → energy
- Time of flight → position
- Pulse shape → α/β β^+/β^-



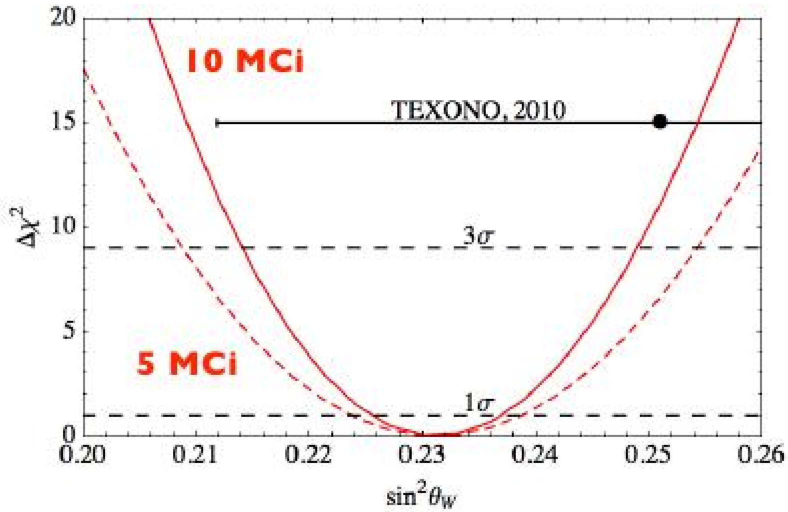


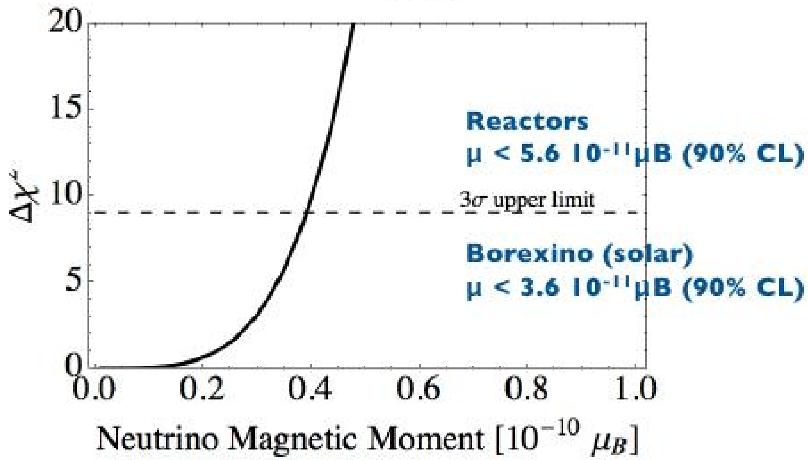
- Energy resolution:
  - 10% at 200 keV
  - 8% at 400 keV
  - 6% at 1 MeV
- Vertex resolution:
  - 35 cm at 200 keV
  - 16 cm at 500 keV

Chronology: Artificial Neutrino Source

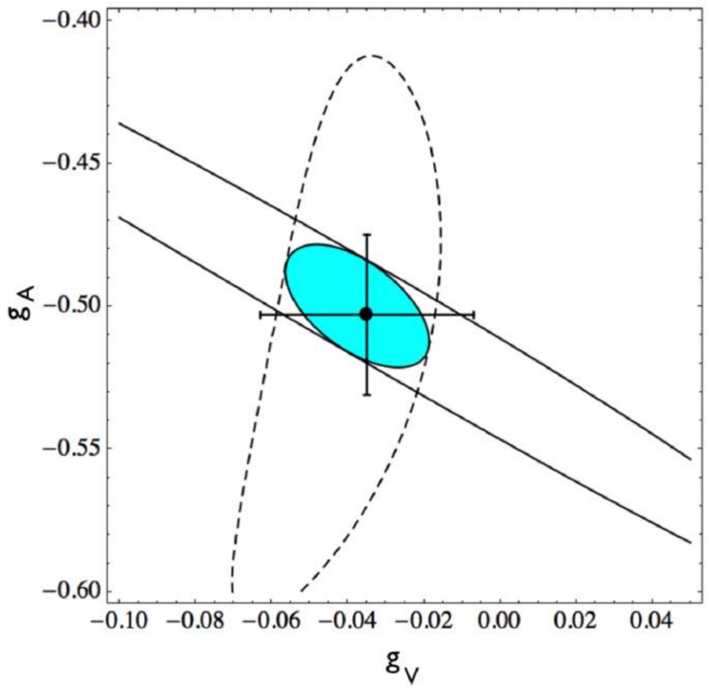
- The idea to deploy a source in Borexino dates back to the beginning of the project
- Successfully implemented by Gallex (LNGS) and SAGE (Russia)
- Recently, revised and re-proposed by many authors to search for sterile neutrinos:
  - N.G. Basov, V. B. Rozanov, JETP 42 (1985)
  - Borexino proposal, 1991 (Sr90)
  - J.N.Bahcall,P.I.Krastev,E.Lisi, Phys.Lett.B348:121-123,1995
  - N.Ferrari,G.Fiorentini,B.Ricci, Phys. Lett B 387, 1996 (Cr51)
  - I.R.Barabanov et al., Astrop. Phys. 8 (1997)
  - Gallex coll. PL B 420 (1998) 114 Done (Cr51)
  - A.Ianni,D.Montanino, Astrop. Phys. 10, 1999 (Cr51 and Sr90)
  - A.Ianni,D.Montanino,G.Scioscia, Eur. Phys. J C8, 1999 (Cr51 and Sr90)
  - SAGE coll. PRC 59 (1999) 2246 Done (Cr51 and Ar37)
  - SAGE coll. PRC 73 (2006) 045805
  - C.Grieb,J.Link,R.S.Raghavan, Phys.Rev.D75:093006,2007
  - V.N.Gravrin et al., arXiv: nucl-ex:1006.2103
  - C.Giunti,M.Laveder, Phys.Rev.D82:113009,2010
  - C.Giunti,M.Laveder, arXiv:1012.4356
  - **SOX proposal - ERC 320873 - Feb. 2012 - approved Oct. 2012**

Other low Energy Neutrino Physics





- Weinberg angle
- Magnetic moment
- Coupling constants g_V and g_A (CHARM II: E~10 GeV)



Source Production (GALLEX)

- Natural Chromium consists of 4 stable istotopes

Production steps:

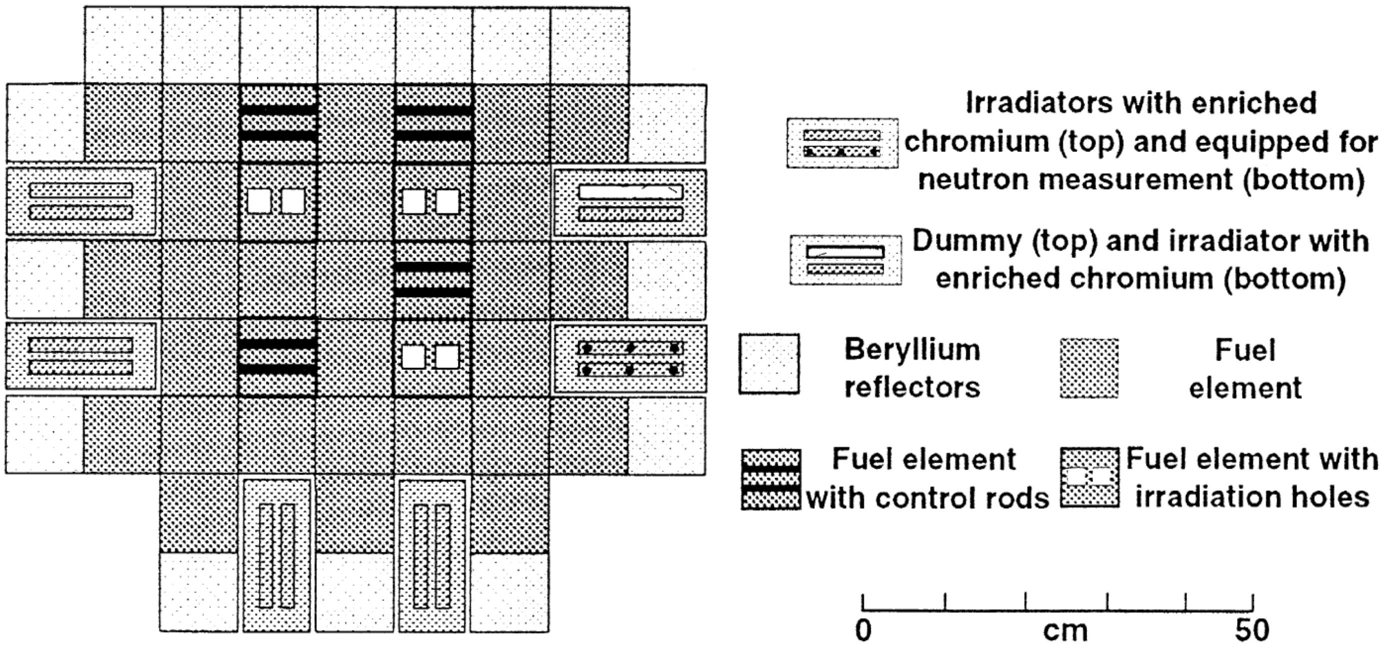
- Chromium isotopic enrichment
  - $CrO_2F_2 \rightarrow CrO_3$
- Chromium irradiation
  - Irradiation @ Siloé (Grenoble, France), swimming pool reactor with 35MW thermal power
  - Dedicated core speciafally built to contain 34 fuel elements
  - Checker-board configuration
  - Core immersed in water (moderator, coolant, shielding)

Table 1:

Isotopic composition of chromium and thermal neutron capture cross-section (measured at 2200m/s)

	Isotopic composition of natural Cr	Isotopic composition of the enriched Cr used in GALLEX	Thermal neutron capture cross-sections (barns)
^{50}Cr	4.35%	38.6%	15.9
^{52}Cr	83.8%	60.7%	0.76
^{53}Cr	9.5%	0.7%	18.2
^{54}Cr	2.35%	<0.3%	0.36

Source Production (GALLEX): irradiation



Physics Letters B 342 (1995) 440-450